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(NASA-CR-170190) ASTRONOMICAL STUDIES OF THE MAJOR PLANETS, NATURAL SATELLITES AND ASTEROIDS USING THE 2.24 m TELESCOPE Semiannual Progress Report, Jan. - Jun. 1982 (Hawaii Univ., Honolulu.) 35 p

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For the Period

January-June 1982

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I. PERSONNEL

This report covers the period January-June 1982. Scientific personnel engaged in planetary research who were supported fully or in part by this grant during the period are as follows:

W. M. Sinton	D. Morrison	C. B. Pilcher
D. P. Cruikshank	J. Goguen	R. R. Howell

In addition, graduate students D. Backman, J. F. Morgan, and M. Pierce received salary support on research assistantships. A summer student, G. S. Aldering, was also supported through this grant.

II. THE RESEARCH PROGRAMS

A. HIGHLIGHTS

1. Discovery that directional features in the Jovian sodium torus originate not from a specific point on Io's surface, but are instead related to a more general source of high-speed sodium and the effects of the electron-impact ionization sink provided by the plasma torus.
2. Acquisition of high-quality CCD images of the major planets, including images of Neptune in the 8900 Å methane absorption band showing bright polar regions.
3. Discovery that the methane bands in the spectrum of Triton are variable, suggesting that they are caused by solid methane in a nonuniform distribution on the satellite's surface.
4. Precise determination of the central wavelength of the SO_2 absorption band on Io, indicating that the band arises from solid SO_2 rather than adsorbed gas.
5. Confirmation of a dark, spectrally neutral component on the otherwise icy surfaces of the satellites of Uranus.
6. Discovery that Io's volcanic radiation at 4.8 μm may fluctuate on a time scale of at least a year. The mean brightness of Io at 4.8 μm from this year's observations is 20% less than either of the two previous years and leads to the conclusion of long-period fluctuations.
7. Inception of a program to improve substantially the number and accuracy of 3.8- and 4.8-μm standard stars. Revision of the standards is necessary to improve the accuracy of the Io fluctuation measurements.
8. Detection for the first time of thermal radiation from the four brightest satellites of Uranus; from these data diameters and albedos have been determined.

B. THE MAJOR PLANETS

1. Jovian Magnetospheric Studies

Although we had planned to begin the next observational phase of our Io torus studies using the CCD in 1982, the combination of the atmospheric effects of the El Chichón volcanic eruption and the time required to reduce and analyze data already in hand led us to postpone additional observing until 1983. Since El Chichón is at essentially the same latitude as Hawaii, the initial spreading of the high-altitude cloud to the west resulted in the rapid covering of Mauna Kea by a substantial atmospheric scattering layer. Low atmospheric scattering is important for observations of the faint torus emissions in the glare of nearby Jupiter, so it is likely that data acquired during 1982 would have been substantially inferior to those that will be obtained after the cloud has had some time for dissipation. In combination with our substantial backlog of image-tube data, this fact induced us to concentrate on the reduction and analysis of data already in hand.

As part of this effort, Pilcher and Research Associate J. Fertel have essentially completed the reduction of images acquired in 1980 and 1981 that show directional features in Io's sodium cloud. With the full data set now available in quantitative form, it has become possible to discern systematic variations that point strongly toward one of two alternate theories for directional feature formation. We had previously noted that the majority of the features are directed away from Jupiter and to the north of Io's orbital plane. However, all such observations were obtained when Io was between 170° and 330° magnetic longitude. In the few observations we have at other longitudes, the features are generally directed away from Jupiter and toward the south, and are sometimes associated with a morphologically distinct, narrow feature directed toward Jupiter and slightly to the north. In one particular-

ly diagnostic sequence (Figs. 1-3), the symmetry axis of a directional feature was observed to shift from south to north during a four-hour interval as Io traversed an apparent magnetic boundary region centered near 150° longitude.

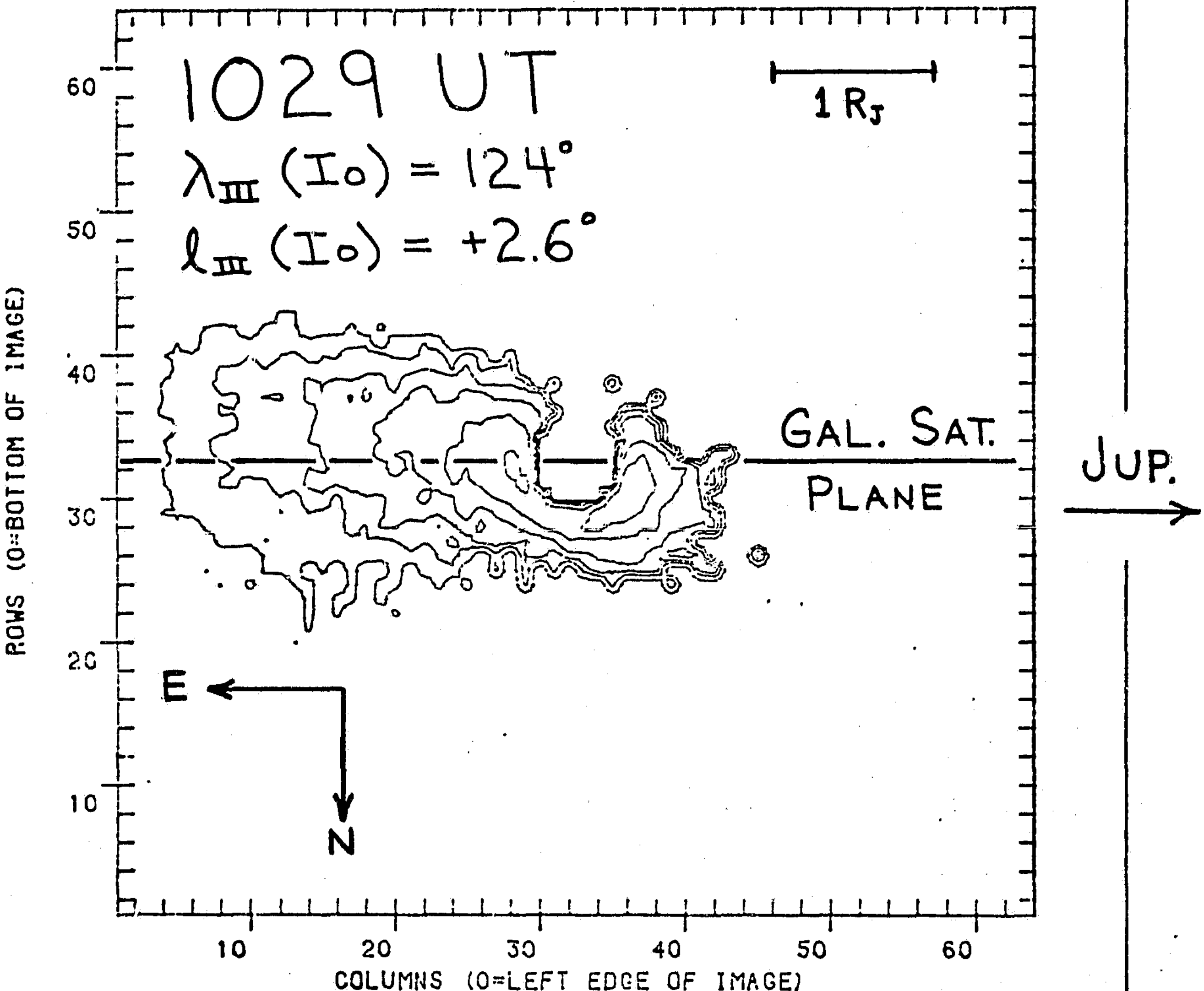
This behavior indicates that the features are not associated with any region on Io's solid surface, but rather are the result of a balance between a more general sodium source and the electron-impact-ionization sink provided by the plasma torus. Pilcher and W. H. Smyth of AER, Inc. (Cambridge, MA) will collaborate on the development of a model to account for the observed feature characteristics.

Pilcher and Fertel have also completed much of the reduction of images of the SII component of the plasma torus acquired in 1981. In addition to the data presented in the Io torus movie, we acquired data on five other nights in 1981. These data include images on two nights immediately preceding that of the movie, as well as a second lengthy sequence (32 images in 8 hours) obtained a month later with images on two surrounding nights. The additional data show substantial differences from those presented in the movie. The field-aligned feature (FAF) in the movie data is much more prominent than the images acquired a month later, although the variation in the FAF relative intensity with magnetic longitude is similar in both groups of data. In the movie, the FAF is 0.3-0.4 R_J closer to Jupiter than it was on the preceding night. A portion of these and other variations among our data may be due to temporal changes, but we suspect that systematic spatial variations may also be involved. The completion of the reduction of the remainder of our 1981 plasma images and their detailed analysis should shed light on this question.

For his dissertation, Morgan has been reducing and analyzing low-resolution spectra of the Io torus. From a brief review of the literature, it is easy to see that there is a wide range of intensities reported for the [SII]

SODIUM 2.5 deg. tilt 1/6/80 KD1069C

filter transmission at 1.5 degrees used for correction



Contour levels at:

65.00
125.00
175.00
250.00
400.00
700.00

Fig. 1. Contour plot of an image in the sodium D2 line showing a feature inclined toward the south (upward) of Io's orbital plane. Io is centered under the 14-arcsec (0.7 R_J) occulting disk which appears in the center of the plot as an incomplete octagon. Io's magnetic longitude and latitude at the time of observation are shown in the figure legend.

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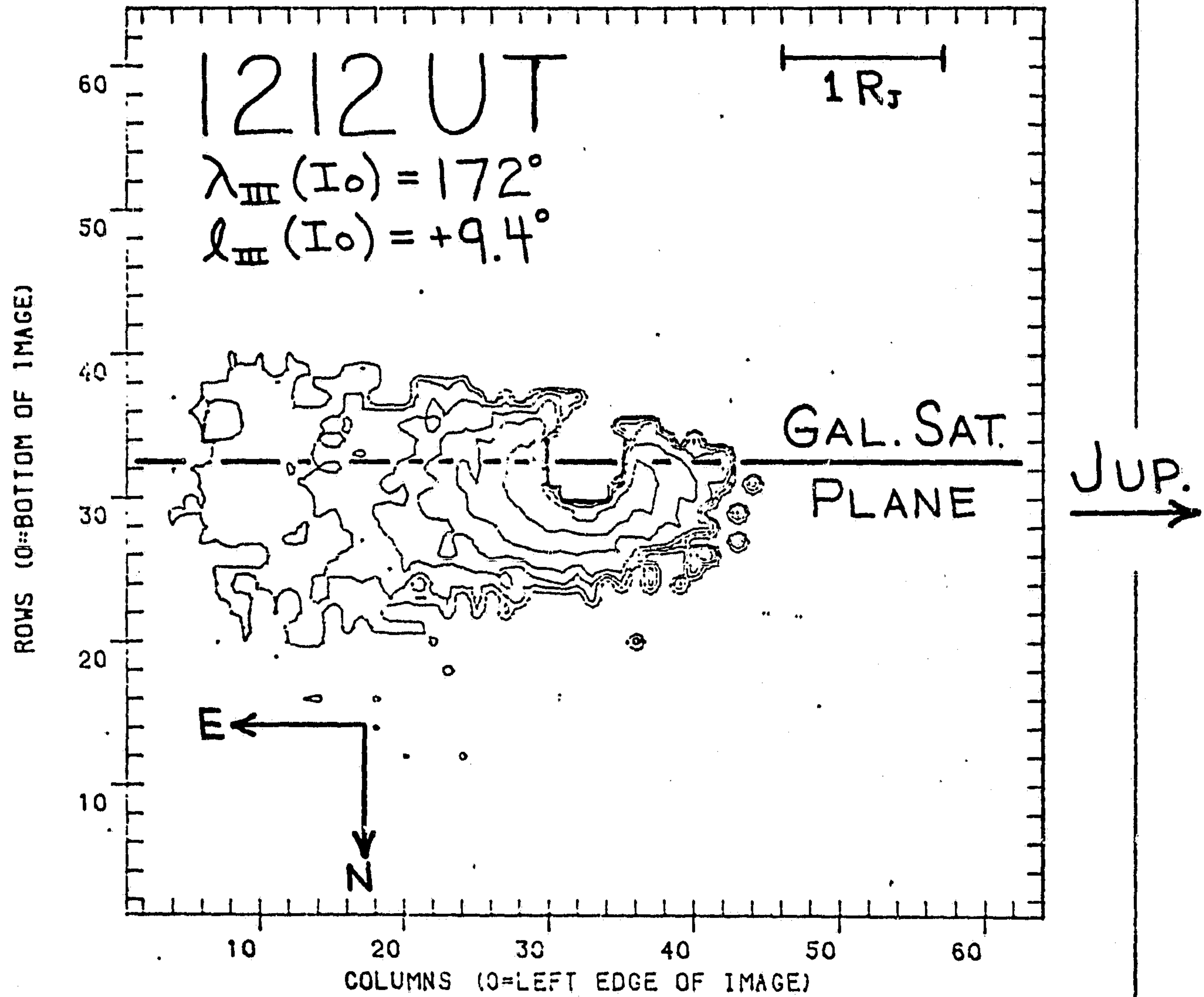
filter transmission at 1.5 degrees used for correction



Contour levels at:
65.00
115.00
175.00
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400.00
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Fig. 2. Same as Fig. 1, but for an image acquired 1^h 53^m later. The features are now inclined toward the north.

SODIUM 2.5 deg. tilt 1/6/80 KD1076A
filter transmission at 1.5 degrees used for correction

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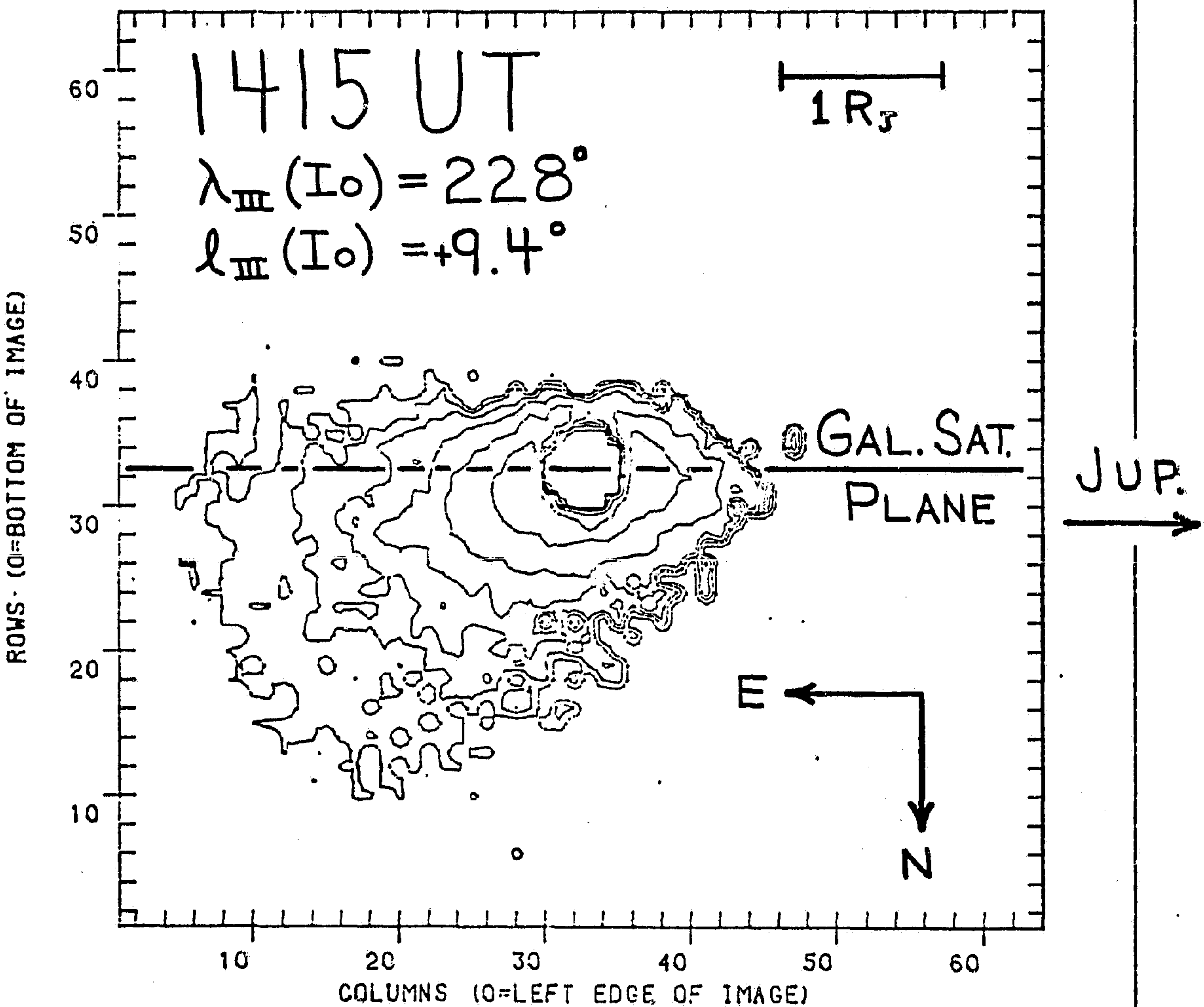


Contour levels at:
65.00
120.00
175.00
250.00
400.00
800.00

Fig. 3. Same as Fig. 1, but for an image acquired 2^h 3^m after that of Fig. 2. The feature is now inclined further to the north.

6716, 6731 emissions. Some of this variation results from observers using apertures that were not completely filled by the torus image. The remainder is often attributed to intrinsic variations in the torus. The absolute value of the emission intensities is important because the ratios of optical to extreme ultraviolet (EUV) intensities are often used to determine plasma temperatures and densities. Such ratios are also used in arguments concerning energy transfer between ionic species. Since the optical and EUV lines are never measured with the same instrument, the absolute calibrations are very important. Also, the emission intensities are the only remote information about the total abundance of a particular ionic species. Morgan can make meaningful comparisons of his data with measurements from other studies because he has a large data base (~1000 measurements of the torus taken over a four-month period in 1981). The significance of spatial and temporal variations may be tested by looking at fluctuations from the mean in his data. Many of his measurements were taken within a few days of the measurements of Brown and Shemansky (Ap. J. 263, 433, 1982). He has also acquired measurements of the Ring Nebula that may be directly compared with previous observations (Hawley and Miller, Ap. J. 212, 94, 1977). There is good agreement with these earlier data, but Morgan has concluded that some of the variations in the Io torus intensities are due to calibration errors, since there seem to be inconsistencies between the average and peak intensities that he measures and those reported by Brown and Shemansky.

Morgan has shown, however, that there are real temporal variations in both the line ratios and intensities. As evidenced by the [SII] line ratios, the nebula can change significantly within a week. Daily variations were not detected but may exist. These results confirm and extend the indications of temporal variations reported in our earlier studies.

No correlation has been found between the [SII] line ratios and the [SII] intensity. This is unusual because the [SII] doublet ratio is sensitive to electron density and fairly insensitive to electron temperature. High densities should produce bright emissions. Brown and Shemansky observed that the [SII] intensity was highly variable although they detected no line ratio variations in their data. They concluded that the intensity variations were caused by variations in the SII mixing ratio. It is unlikely that this could be causing the intensity variations in Morgan's data because he observed regions of the torus that were measured to be mostly SII by the Voyager plasma science experiments. It is hoped that a comparison of the other emissions observed will shed further light on this problem.

2. Major Planet Atmospheres

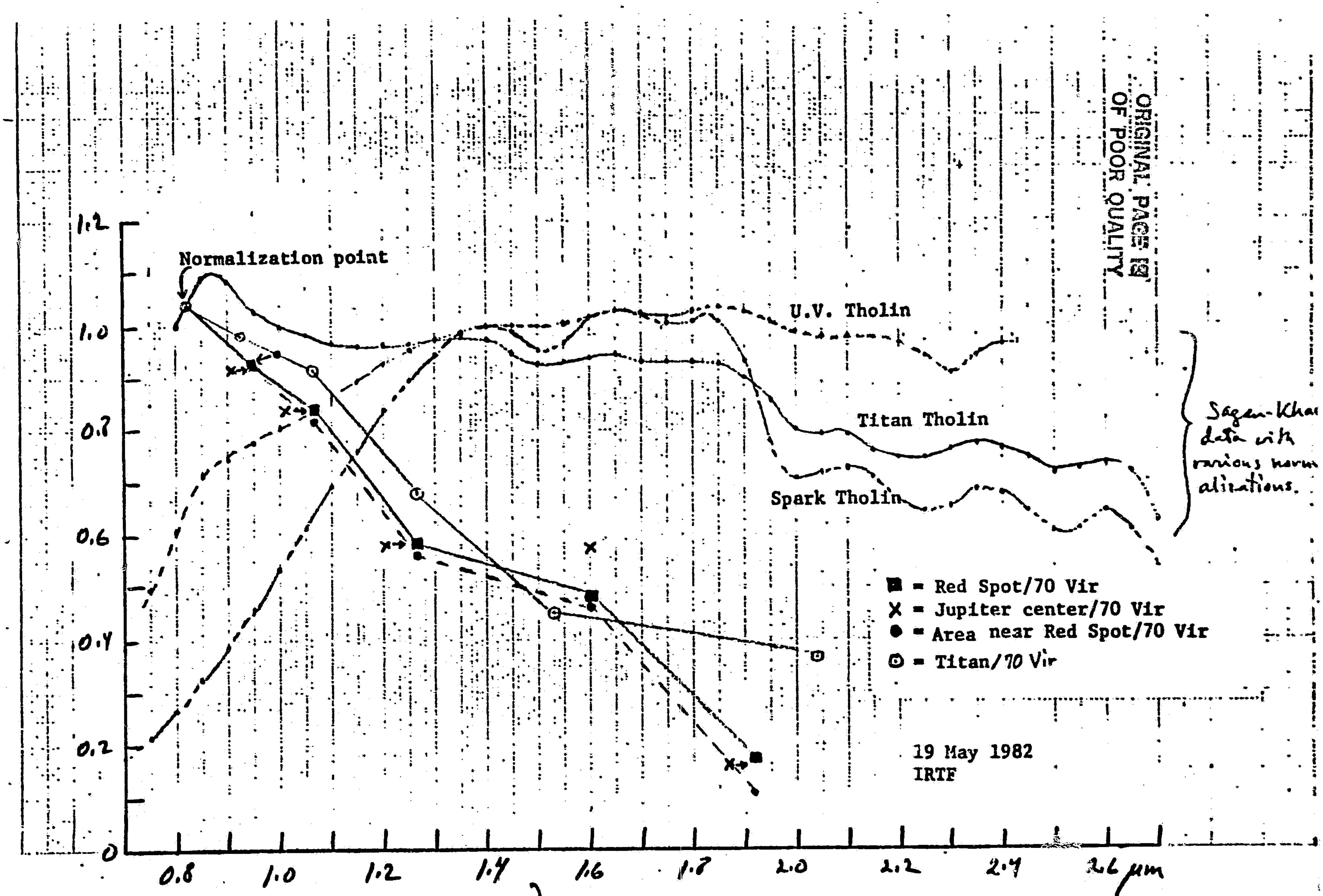
a. CCD Studies

In August 1981, we obtained very limited and somewhat marginal images of Uranus and Neptune at the 2.24-m telescope during the first observing run with the CCD. These have been superceded by much higher quality data for all four major planets obtained by Pilcher and Howell on the same telescope during March and June of this report period. Images were obtained in the three methane bands at 6190, 7250, and 8900 Å, and in the continuum at 6300 and 8200 Å. The methane-band Jovian images generally show a bright south polar hood, a fainter north polar hood, and a considerable amount of structure at equatorial and temperate latitudes including a bright GRS. The methane-band Saturn images show two bright mid-latitude bands that are faintly discernible as dark features in the continuum data. Since the previous imaging study of Saturn at these wavelengths was conducted in 1979 a few months before ring-plane crossing (West et al., Icarus 51, 51, 1982), our data show a hemisphere of the planet never before clearly observed by means of these techniques. The

Uranus and Neptune images, like those of Jupiter and Saturn, were obtained in 1-2 arcsecond seeing. Since these planets have diameters of only 4 and 2 arcseconds, respectively, the detail discernible on their disks is faint. The Uranus images in the 8900 Å methane band show a flat intensity distribution over the central three-fourths of the disk's diameter. When the seeing is taken into account, this indicates extreme limb brightening as expected from earlier studies by us and others. The Neptune images at the same wavelength show faintly the polar brightening seen in 1979 by investigators at the University of Arizona. Since both the Uranus and Neptune frames contain images of point sources (the Uranian satellites and Milky Way stars within the Neptune fields), Pilcher and Howell intend to investigate the application of image restoration techniques to bring out detail on these planets.

b. Spectrophotometry of the Jovian Red Spot

Cruikshank used the IRTF in May 1982 to obtain spectrophotometric observations of the Great Red Spot of Jupiter in the region 0.82-2.57 μm using the new 3% passband CVF and the 5% passband CVF acquired earlier. In these observations, in which Morrison and (then) student R. H. Brown participated, he used an aperture of 2 arcseconds in order to isolate the GRS. Observations of adjacent regions in the Jovian clouds were also made for comparison. The results show that in the spectral region covered there is little if any perceptible difference in the color of the GRS and the surrounding clouds, that is, the GRS is grey in the near infrared. At the resolution and signal precision achieved, there is apparently no spectral signature that will give a definitive identification of a coloring species in the GRS. This work was undertaken to search for spectral signatures of the sort found by B. Khare and C. Sagan in their laboratory studies of tholin compounds. The Jupiter data are plotted in Figure 4 for comparison with the laboratory spectra of the



Normalization point
U.V. Tholin
Titan Tholin
Spark Tholin
Sagan-Khare data with various normalizations.
■ = Red Spot/70 Vir
X = Jupiter center/70 Vir
● = Area near Red Spot/70 Vir
⊙ = Titan/70 Vir
19 May 1982
IRTF
1.2
1.0
0.8
0.6
0.4
0.2
0
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6 μm
λ

Fig. 4

tholins provided by Drs. Khare and Sagan. Additional analysis of the problem is in progress with these two colleagues.

C. SATELLITES AND PLUTO

1. Spectroscopy of Triton

Spectrophotometric observations of Triton were made by Cruikshank in May 1982 with the IRTF and a new circular variable filter (CVF) having a passband of 3-4% in the region 0.8-1.6 μm. This work was undertaken to explore for the first time the spectrum of Triton in this spectral region, thus augmenting the earlier spectral data obtained by Cruikshank from 1.5-2.5 μm. The combined spectrum, a composite from several different observing runs in different years, is shown in Figure 5. Shown for comparison are a laboratory spectrum of methane ice and a synthetic spectrum (courtesy of Dr. J. Apt) of methane gas computed for the low temperature and low pressure appropriate to Triton conditions. The Triton spectrum shows six absorption bands attributed to methane, probably in the solid state, plus an additional absorption band centered near 2.15 μm that is presently unidentified. The original discovery of methane on Triton (Cruikshank and Silvaggio, Ap. J. 233, 1016, 1979) is thus confirmed, as is the presence of the 2.15-μm feature reported by Lebofsky et al. The unidentified feature is seen in several of the individual spectra as well as in the coadded composite shown in the figure.

Although the new observations in Figure 5 appear to show the 0.89-μm methane band rather clearly, some other observers, notably the Arizona group, have been unable to see it at higher resolution. The strength of the 2.3-μm band of methane indicates that the 0.89-μm feature should be visible, but prior to the work reported here, it had not been detected. To help settle this outstanding controversy, which bears on the identification of methane as the absorbing molecule, Pilcher and Cruikshank obtained spectra at substan-

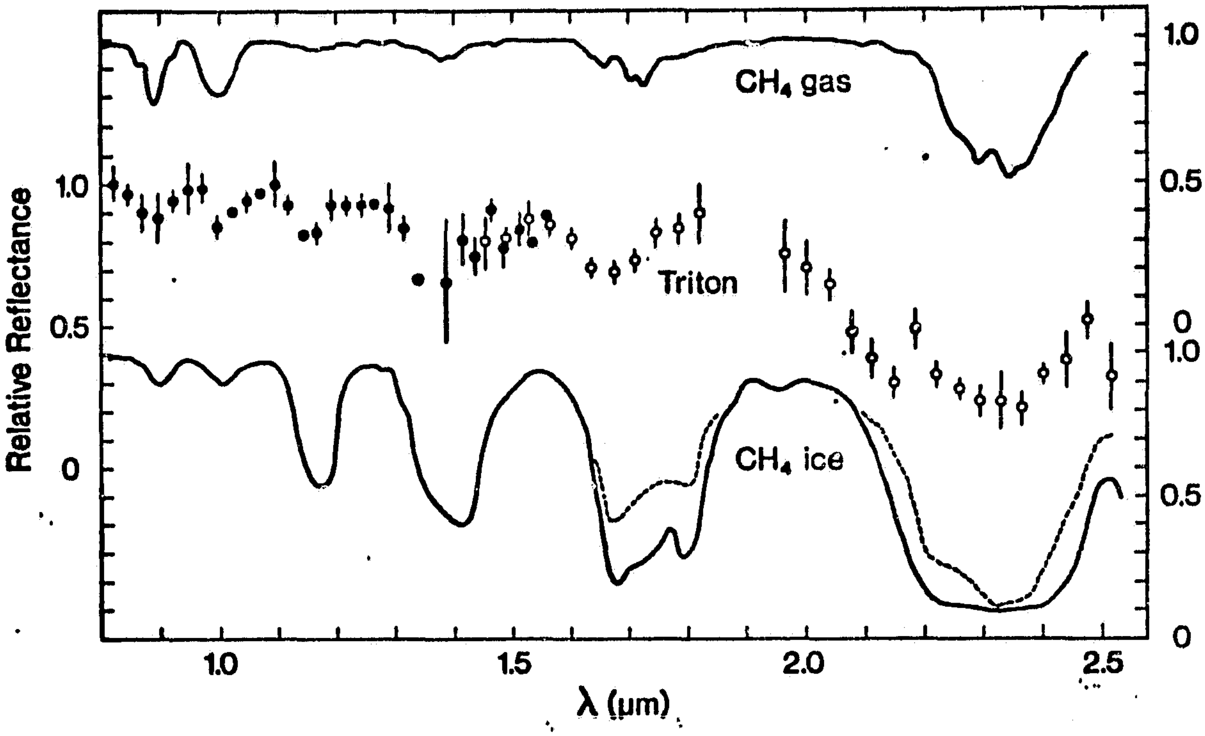

CH$_4$ gas
Triton
CH$_4$ ice
Relative Reflectance
1.0
0.5
0
1.0
0.5
0
1.0
0.5
0
1.0
1.5
2.0
2.5
λ (μm)

Fig. 5

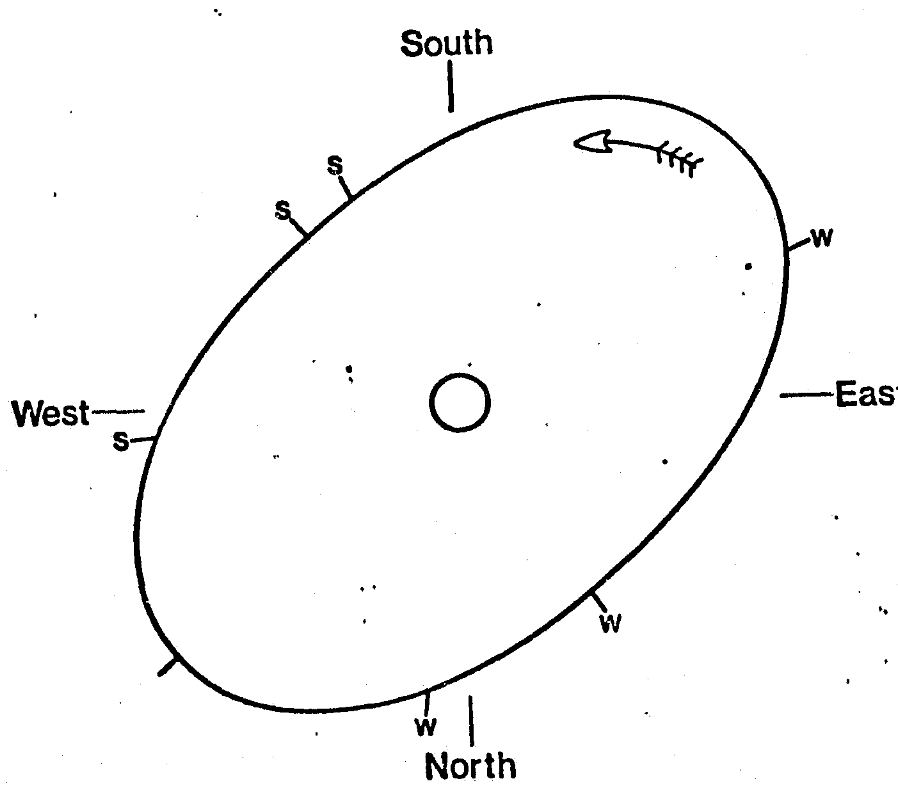

South
North
West
East
s
s
s
w
w
w

Fig. 6

tially higher resolution with a transmission grating spectrometer using the CCD as a detector. The spectrometer and detector system were fashioned with the considerable help of Dr. Alan Stockton, who uses the system for spectroscopy of faint extragalactic objects.

Triton spectra were obtained with the CCD spectrometer on the 2.24-m telescope on three successive nights in June 1982. When compared with synthetic spectra provided by Dr. J. Apt, a weak absorption at 0.89 μm may appear in the data of at least one of the nights.

In studying the Triton spectra obtained with CVF spectrometers over the past five years, Cruikshank noted that the absorption bands are variable in strength. The data set is not entirely homogeneous, thus obscuring the pattern of variability, but a pattern in fact emerges when the data are arranged according to orbital phase angle of the satellite. The orbital period of Triton is 5.88 days, and the satellite is expected to be in locked synchronous rotation. The satellite thus displays different portions of its surface at different positions in the orbit. The methane bands are strongest when Triton is in the southern and western portions of the orbit, and weakest when it is in the northern and eastern sectors. This distribution is derived on the basis of the infrared CVF spectra; the weak absorption shown in the CCD spectrometer data on one and possibly two nights is consistent with this distribution.

The variability of absorption strengthens the conclusion derived from the spectral data that the methane is in the solid state and that it is distributed nonuniformly over the surface. Figure 6 (see p. 13) shows the distribution of the data acquired so far. This conclusion requires further verification from a more homogeneous set of observations. This is the goal of an observational program planned with the IRTF in 1983.

The confirmation of methane on Triton and the identification of the solid state bears on the comparison of Pluto and Triton and on studies of their atmospheres. Methane gas must coexist with methane ice on both bodies, and studies of the atmospheres are in progress by Cruikshank and colleagues.

2. Spectroscopy of Pluto

Cruikshank also obtained spectra of Pluto with the new CVF in the region 0.8–1.6 μm. The methane absorptions found on Triton in this region are also found on Pluto, where they are significantly stronger. Taken together with other spectra out to 2.5 μm, the composite spectrum of Pluto once again confirms the presence of methane in significant abundance. Some investigators have argued that the absorption is chiefly gaseous in nature, but the strength of the bands, particularly at 1.7 and 2.3 μm, argues in favor of a substantial frost component on the surface. Further, the fact that Pluto has a strong lightcurve would support the precept that methane frost is distributed nonuniformly on the planet's surface, as in the case of Triton.

Further observations are planned for 1983 to help resolve the question of Pluto's surface and atmosphere. The spectra obtained in 1982 will be combined with the anticipated new data to present a more satisfactory combined spectrum in the 0.8–2.5 μm region taken at specific points in the (rotational) lightcurve.

3. Io Thermal Studies

Using the 2.24-m telescope, Sinton has continued his monitoring of the near-infrared thermal emission from the volcanoes. The aims of this program have been to study the time history of an outburst, to confirm the tentative correlation of activity with magnetic longitude that was found in the first two years of data, and to study the "flickering" of the volcanoes in more detail. Disappointment came in one sense when, beginning with the January

observations and continuing through the opposition, it was found that Io's 4.8-μm flux was substantially less than for the previous two oppositions. No outburst that met the outburst criterion of a "geometric albedo" > 1.2 at 4.8 μm was found. Only one minor flux elevation was found after adoption of a criterion based on 1982 mean albedos. Studies of the rapid flickering were made, and some periods of significant flickering were found.

But in a broader sense, we have seen more of the variability of Io's volcanism, and we now realize that decreases have as much significance as increases. The mean geometric albedo at 4.8 μm was ~20% less than either of the previous year's means. Thus it was found that Io varies over relatively long periods of time as well as short periods.

The single mild flux elevation, on 4 February 1982, could be analyzed in regard to color temperature by subtracting 1982 mean 3.8- and 4.8-μm fluxes from those observed during the event. At the start of observations, the color temperature was 650 ± 30 K and remained sensibly constant for an hour with a 20-km diameter for the equivalent circular area. During the next hour, the temperature dropped to ~520 K and the area expanded to a ~35-km diameter and again seemed to remain constant until the end of observing more than an hour later. The largest expansion velocity was ~7 km h^{-1}, very slow compared to the ~100 km h^{-1} velocities found in previous outbursts (Sinton et al., Icarus, 1983, in press). This is one of the best observed events with seven color temperatures and apparent areas determined during the 3 h 20 m period of observation that was restricted by the late hour at which Jupiter rose.

Sinton and Charles Kaminski (IRTF telescope operator) are collaborating on a program to observe eclipses of Io at seven wavelengths between 3.5 and 30 μm. Only one eclipse could be observed this spring; weather marred about four others that were attempted. The one observed, an eclipse disappearance

on 19 March 1982, furnished good data on the eclipse cooling part of the curve. These are the first observations of the cooling part of the curve, and they will help to define the thermal models that are required to separate volcanic radiation from the radiation of the eclipse-chilled surface.

4. Io 4-μm Spectroscopy

During the first half of 1982, Howell continued the observations of the 4-μm region of Io's spectrum. At this wavelength, the satellite exhibits a deep absorption band believed to be caused by SO_2. Two outstanding questions concerning the band are its exact wavelength and the possibility of temporal variations in its strength.

The wavelength of the band may be diagnostic of the form of the SO_2 on Io, but reports of the observed band center have ranged from 4.03 to 4.08 μm. Those discrepancies apparently result from small systematic errors in the calibration of the CVF spectrometers that have been used. However, some researchers have suggested that the band position actually varies with the longitude we see due to varying relative amounts of adsorbed SO_2 and SO_2 frost.

To determine accurately the wavelength of the band, we observed Brackett α emission objects (typically compact planetary nebulae) on the same nights we observed Io. The Br α line at 4.052 μm is nearly coincident with the SO_2 band and allows one to remove the systematic calibration errors. Our observations show that the band on Io is centered at 4.055 ± 0.050 μm and there are no wavelength shifts with longitude greater than 0.01 μm. Figure 7 shows the superposed Br α and Io spectra.

A comparison of the 1981 spectra with those of 1976 suggested the possibility of temporal variations in the band strength. However, the 1981 observations did not precisely match the longitude of the earlier ones and the

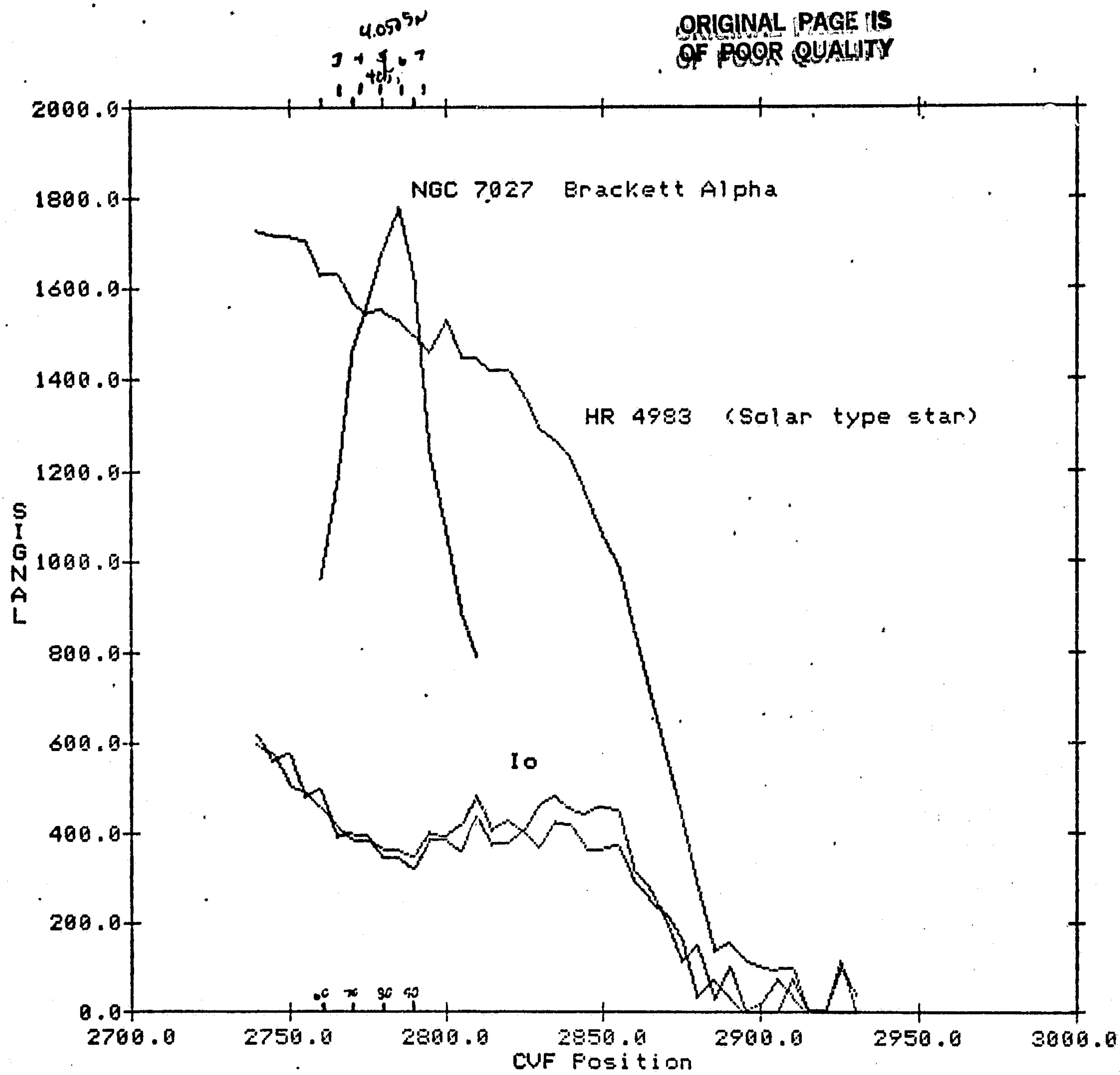

NGC 7027 Brackett Alpha
HR 4983 (Solar type star)
Io
SIGNAL
CVF Position
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
2700.0
2750.0
2800.0
2850.0
2900.0
2950.0
3000.0

Fig. 7

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effect may have been due to a sharp longitudinal variation. To distinguish between these two cases, we obtained spectra this spring that did match the longitude of the 1976 ones. They show that the effect is in fact due to the longitudinal variations. Any temporal changes in band strength must be less than 20%. This supports the conclusion of Morrison et al. (Nature 280, 725, 1979) is that the global albedo pattern of Io is stable over long periods of time. However, the much smaller albedo changes seen by Lockwood et al. (Icarus 44, 240, 1980) are below our detection limit.

Finally, we attempted to observe Io at these SO_2 wavelengths during eclipses. Most of those attempts were foiled by poor weather, but one somewhat unfavorable eclipse reappearance was observed. It showed that the thermal emission at 4 μm is weak enough that our measurements of band strength and position will not be affected except during major outbursts. Our work during the second half of 1982 concentrated on obtaining laboratory spectra of SO_2 and on analyzing the Io data in light of those lab spectra.

5. Spectrophotometry of the Satellites of Uranus and of Hyperion

In work supported partially by this grant, new reflectance spectra at 3% resolution were obtained with the new CVF for Ariel, Titania, Oberon, and Hyperion in the 0.8-1.6 μm spectral region. This work was performed largely by R. H. Brown as a portion of his Ph.D. thesis work, in continuation of spectrophotometry done at longer wavelengths in the previous year by Brown and Cruikshank. The new spectra show no absorptions other than the 1.5-μm water-ice feature and demonstrate again the spectral similarity of Ariel to Hyperion noted in earlier work by Brown and Cruikshank. The new data confirm the presence of a dark, spectrally neutral component in or on the water-ice surfaces of the Uranian satellites. Brown has compared the spectrophotometric data with spectra of additive reflectance mixes of fine-grained water frost

and various dark components such as charcoal, lampblack, and mixtures of charcoal and water ice. The results set broad limits on the amounts of areal coverage of a possible charcoallike component on the water surfaces of the satellites. Good spectral matches for Hyperion, Ariel, Umbriel, Titania, and Oberon were produced from additive spectral mixtures of fine-grained frost and an intimate mixture of 70% charcoal and 30% water ice by weight, but the data are not sufficiently precise to permit a determination of the nature of the contamination.

The IR photometry by Brown and Cruikshank shows the four large satellites of Uranus have enormous opposition effects, increasing in brightness by as much as 0.7 magnitudes in 3° of phase angle. Goguen and Brown tried to confirm these observations with V photometry during 1982, but weather conditions resulted in an incomplete data set. The data obtained suggest that the large opposition effect is real and of a similar amplitude in the V as in the IR. Completion of the necessary observations is planned in 1983. Brown used this work in his Ph.D. dissertation, which was satisfactorily defended on 12 November 1982.

6. Spectrophotometric Studies of the Dark Hemisphere of Iapetus

In a coordinated effort to obtain new and improved spectrophotometric data on the dark hemisphere of Saturn's satellite Iapetus, Cruikshank and Howell, together with graduate student J. Bell, received telescope time on the UKIRT 3.8-m, the IRTF 3.0-m, and the UH 2.24-m telescopes at the end of March 1982. The intent was to cover with the various telescopes three overlapping spectral regions ranging from 0.3 to 4.1 μm. The well-laid plans were thwarted by cloudy weather throughout the three-night apparition of the dark hemisphere of the satellite, and no new data resulted.

Plans have been made for another attempt with the same three telescopes at a favorable opportunity in mid-February 1983.

7. Hyperion

S. Peale (in Planetary Satellites, Burns, Ed.) has shown that Saturn's satellite Hyperion is perhaps the only major satellite that may not be locked in synchronous rotation about its primary. Voyager observations show Hyperion's nonspherical shape and are consistent with nonsynchronous rotation states. Due to its elongated shape, Hyperion is expected to exhibit large brightness variations with rotation. Photometry of Hyperion to determine its rotation period was undertaken with the 2.24-m and 0.6-m telescopes. However, due to its faintness (V ~ 14.6) and proximity to Saturn, the numerous 0.6-m measurements are of insufficient accuracy. The 2.24-m data are of high quality, but too sparse. A concentrated effort with the 2.24-m telescope is planned in 1983. When our 1982 data are combined with observations by D. Tholen and W. Wisnieski, a sizable opposition surge is suggested.

D. ASTEROIDS

1. The Figures and Rotation Periods of Trojan Asteroids

Studies of the dynamics of asteroids and their rotation periods (chiefly by Weidenschilling, Burns, and Harris) show that for plausible internal compositions the periods cannot be shorter than about three to four hours; this is in agreement with the shortest rotation periods found from observations. The Trojan families of asteroids are a special case where the dynamical (collisional) evolution with consequent fragmentation and spin-up is modeled in terms of very low-energy collisions. Cruikshank and W. K. Hartmann (PSI, Tucson) have studied the shape and rotation of 624 Hektor in considerable detail and conclude that it may be contact binary object resulting from a low-energy collision. Other similar objects may exist, and the frequency of their occurrence is an important observational input to the modeling of the mutual interactions of the Trojans.

Hartmann and Cruikshank (with the assistance of Goguen) have begun a photometric study of the lightcurves of other Trojan asteroids in order to explore the systematics of their shapes (via the lightcurve amplitudes) and rotation periods. This work is in progress with the 2.24-m telescope and the refurbished Tinsley photometer. The improvements on the photometer have been made with funds from this grant in previous years and include automation for operation from the control room of the 2.24-m telescope, a new cold box, and a GaAs phototube. Preliminary results (obtained in February 1982) show that the photometer is very sensitive and has low noise characteristics. When fully operational with complete remote control, the photometer will permit efficient and precise observations of faint solar system and stellar objects, giving us a capability that we did not formerly have at the 2.24-m telescope. The photometer can also be used at the 0.6-m telescopes using a portable data system built around an Apple II computer, also purchased with this grant in an earlier year for this purpose.

The observations already obtained for Trojan 884 Priamus ($m_V \sim 17$) show that it has a lightcurve of amplitude 0.3 mag and a period between six and eight hours. Precise determination of the period will result from a more detailed analysis of the observations already in hand, but even a rough number is useful for the modeling studies. The amplitude of 0.3 mag indicates an irregular shape, and this can also be modeled using techniques already developed.

Additional work on the 617 Patroclus (also $m_V \sim 17$) shows no appreciable lightcurve, indicating that its amplitude is less than 0.1 mag. A spherical or near-spherical shape is thus supposed, indicative of few or no major collisions during its lifetime. We will work more on Patroclus to refine the observational limit on the amplitude and possibly to measure the period.

Each of the Trojan clouds contains about six to eight objects for which photoelectric photometry can be obtained with the 2.24-m telescope, though the work is relatively slow because of the faintness of these bodies. We have made a good start and propose to continue the work until the periods and lightcurve amplitudes of the total of 12 to 14 brightest Trojans have been observed.

2. 3-μm Spectra of Selected Asteroids

The spectral region 2.3-4.2 μm contains important information on the chemical compositions of asteroid surfaces. In this region, the water of hydration present in some minerals (e.g., the clays) shows a strong and characteristic absorption. Water ice in very small concentrations also shows distinguishable features, and carbonaceous material reveals its presence through the C-H absorption at about 3.4 μm. Indeed, L. A. Lebofsky and colleagues have reported on their observations of the hydrated mineral band and also identify a small feature at 3.05 μm as due to water ice in small amounts on the surface of 1 Ceres. Our data for Ceres also show the water hydration and the 3.05-μm feature, but we are rather cautious about the ice interpretation. We are not convinced that the wavelength is exactly correct (the water ice feature reported by Lebofsky and colleagues lies at 3.10 μm while the Ceres feature is at 3.05 μm), and the implausibility of stable water ice at Ceres' distance from the sun (2.77 AU) reinforces our suspicion. The spectral feature is present, however, and we wish to study other asteroids in the same region in search for other occurrences.

The same spectral region includes the C-H stretch absorption band found in the spectra of several canbonaceous meteorites (Allende, Felix, Lance, Orgueil). The identification of this feature in the spectrum of an asteroid would add to our understanding of the origin of certain classes of meteorites

and the chemical and dynamical evolution of the asteroids and the material liberated from them by impact events.

The NASA-IRTF and UKIRT telescopes are particularly suited to this spectroscopic work because they have sensitive 3-μm systems (InSb detectors) and good circular variable interference filters. Our work to date (Cruikshank and Howell) has been done mostly with the UKIRT 3.8-m telescope because the extra aperture is needed for work in this spectral region on the relatively faint asteroids. We propose to continue with this work concentrating on the brightest asteroids of various taxonomic types. The detection of the C-H band requires the highest signal-to-noise ratio obtainable--on the order of 0.5 %--and this can be accomplished on only a few of the asteroids of the C or U types which appear to contain the bound water band.

3. Apollo

The earth-crossing asteroid 1862 Apollo had a favorable apparition during May, brightening to V ~14. The 0.6-m telescope was used to measure at least partial V filter rotational lightcurves on seven nights over a range of phase angle α from 15° to 90°. Such large phase angles can only occur for earth-approaching asteroids; main belt asteroids rarely exceed α ~25°. A. Harris (JPL) and colleagues observed Apollo from opposition to α ~15°. Goguen, Hammel, and Harris are collaborating to produce a phase curve for Apollo including the opposition effect and complete to α ~90°. This phase curve will be used to determine the phase integral and Bond albedo of Apollo and to characterize the photometric function of its surfaces layer for comparison to scattering by other solar system surfaces.

E. OTHER RESEARCH

1. 3.8- and 4.8-μm Standard Stars

Sinton began a program of establishing an enlarged set of standard stars

for 3.8 and 4.8 μm. The need for a revised set of standards became apparent when the year-to-year variation of Io was discovered. The California Institute of Technology (CIT) list of standards has only 18 stars with 4.8-μm magnitudes. Of these, only four are fainter than zeroth magnitude. Sinton already has numerous observations of CIT stars to 5th and 6th magnitude as a result of their use as comparison objects for Io flickering measurements. A set of 45 stars has been selected from the CIT list of JHK photometry that gives an ample number of reliable standards at all right ascensions. With the completion of the coverage of the sky, expected next year, the nightly and yearly mean albedos of Io will become more accurate, and long-term measurements of the variability of Io will be more reliable. There have been few observations of standards at 3.8 μm; the measurements have mostly been made at 3.4 μm. Yet, the atmospheric transparency is higher at 3.8. The use of 3.4-μm magnitudes for standards observed at 3.8 introduces an additional uncertainty which will be avoided by establishing 3.8-μm standard magnitudes.

III. OTHER TOPICS

1. In a historical study of observations of the rings of Saturn, Cruikshank, in collaboration with D. E. Osterbrock (Lick Observatory), determined that J. E. Keeler was the first to observe a gap in the outer portion of the A ring in 1888. Osterbrock and Cruikshank published their work in an article in which the case was made for naming the division in the A ring after Keeler.
2. Cruikshank published his historical study of E. E. Barnard's discovery of the fifth satellite of Jupiter. This work is expected to form a part of an eventual book-length biographical study of the life and work of Barnard by Cruikshank.
3. Cruikshank completed a chapter for the book <u>Venus</u> (D. M. Hunten and L. Colin, Eds.) on the history of the development of Venus.
4. Morrison served as a member of the NASA Solar System Exploration Committee.
5. Morrison was the Chairman of the Division for Planetary Sciences of the American Astronomical Society during this period.
6. Pilcher and CCD engineer R. Hlivak attended the Instrumentation in Astronomy IV meeting in Tucson in March 1982 to present the results of their CCD development work.
7. Pilcher continued to serve on the Galileo Imaging Team and as an elected Committee member of the AAS/DPS.
8. Morrison continued to serve on the Voyager Imaging Team and as an Interdisciplinary Scientist on Galileo.
9. Morrison was elected a Councilor of the American Astronomical Society, to take office in 1983.
10. Morrison published his book <u>Voyages to Saturn</u> (NASA SP-451) and has

completed editorial work on the 1,000-page volume Satellites of Jupiter to be published by the University of Arizona Press.

IV. BOOKS AND PAPERS PUBLISHED OR SUBMITTED IN 1982

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V. OPERATION OF THE 2.24-M TELESCOPE

A. TELESCOPE UTILIZATION

Statistics relating to the usage of the 2.24-m telescope are presented in the accompanying table. During 1982, the telescope was used on all clear nights, with a negligible amount of time lost to failure of the telescope, data acquisition computers, or other systems maintained by observatory staff. This high level of reliability is particularly noteworthy since electronics technicians are normally not available during nights or weekends to make repairs.

During 1982, slightly 42% of the observing time was devoted to planetary programs. Half of those observations were carried by members of the Institute for Astronomy staff. The remaining planetary time was used by members of T. B. McCord's group at the University of Hawaii's Institute for Geophysics and by visitors.

B. PROGRESS REPORT--2.24-M TELESCOPE

During the past year, we have continued to make progress in developing electronic detector systems for the 2.24-m telescope. An intensified Reticon system, which is well suited for spectroscopy of faint objects, is now in regular use. This system was constructed at the Institute for Astronomy with support from NSF and the State of Hawaii. There have been several observing runs with the Galileo CCD system, and subarcsecond images have been obtained of objects as faint as R(mag)=25. The testing and operation of this detector are supported jointly by NASA and the State of Hawaii. Finally, we use the multianode microchannel array detectors developed by Gethyn Timothy with NASA support.

We have continued to develop software for the 2.24-m telescope control system and to upgrade the data acquisition system. Support scientist W. Heacox has taken responsibility for the development of software. We have

improved the computer slew, raster scanning, offset, and beamswitch capabilities of the 2.24-m telescope. We now have a CAMAC-based data acquisition system with software that appears to the user to be identical to that in use at the IRTF. With NSF support, we have acquired a tape drive and a Winchester-type fixed disk for the data acquisition system. We hope soon to replace the LSI 11 in the data acquisition system with an LSI 11/23. The expansion in memory from 28 K to 256 K that this change would permit is essential to allow on-line processing of data obtained with array detectors.

2.24-M TELESCOPE USAGE - 1982

Observer	No. of Nights (Planetary)	No. of Nights (Nonplanetary)
Backman	19.1	
Boesgaard		1.0
Bonsack		5.5
Christian		3.5
Cruikshank	18.5	
Dyck		8.0
Goguen	14.5	
Heasley		11.2
Henry		21.3
Howell	6.5	
Impey		18.5
Morgan	2.5	
Morrison	5.0	
Pilcher	11.8	
Rose		21.0
Simon		4.3
Sinton	22.0	
Stockton		16.8
Telesco		2.0
Thompson		8.7
Tully		5.0
Wolff		
Visitors	15.0	57.6
HIG	34.1	
Total	149.0 (42%)	202.0 (56%)

Engineering: 8.0 (2%)